Technical Report SL-93-22
November 1993

US Army Corps
of Engineers
Waterways Experiment
Station

Assessment of Accident at Radford Army Ammunition Plant

by James K. Ingram
Structures Laboratory

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Prepared for U.S. Army Munitions and Chemical Command

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Waterways Experiment Station
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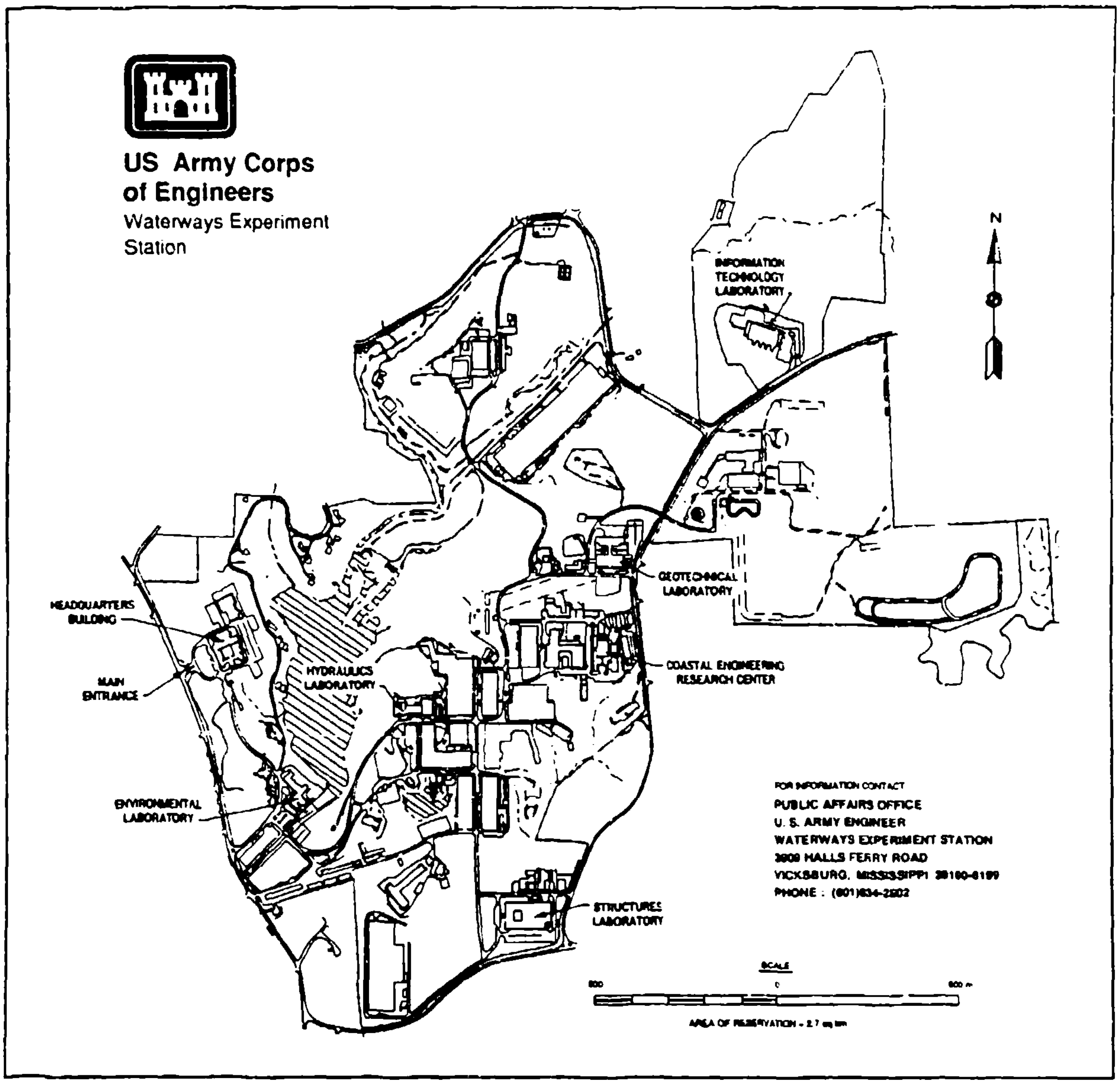
Final report

Prepared for U.S. Army Munitions and Chemical Command
Rock Island Arsenal, IL 61299-6000



Waterways Experiment Station Cataloging-in-Publication Data

Ingram, James K.
Assessment of accident at Radford Army Ammunition Plant / by James K. Ingram ; prepared for U.S. Army Munitions and Chemical Command, Rock Island Arsenal.
14 p. : ill. ; 28 cm. — (Technical report ; SL-93-22)
1. Explosives, Military — Storage — Safety measures — Evaluation. 2. Explosives industry — Illinois — Rock Island Arsenal. 3. Explosions. I. Rock Island Arsenal (Ill.) II. U.S. Army Engineer Waterways Experiment Station. III. Title. IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; SL-93-22.
A7 W34 no.SL-93-22

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Preface

A fatal accident occurred at the Radford Army Ammunition Plant, Virgina, on about 28 March 1988. The fatality was a result of a flash fire and subsequent explosion of a rocket propellant grain being machined to final dimensions. The U.S. Army Engineer Waterways Experiment Station (WES) was asked to conduct a desk study to hypothesize the proble sequence of events which could have led to this incident. Funding for the study was provided by the U.S. Army Munitions and Chemical Command, Rock Island Arsenal, IL, to the Structures Laboratory (SL) WES.

This study was conducted by Mr. James K. Ingram, Explosion Effects Division (EED), SL, WES. During this investigation, Mr. Landon K. Davis was Chief, EED, and Mr. Bryant Mather was Director, SL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
inches	25.40	millimetres

Summary

A desk study was conducted to assess probable sequences of events that could have led to a flash fire and subsequent lethal explosion of a double-base rocket propellant grain being machined to final dimensions. The incident occurred at the Radford Army Ammunition Plant, Virginia, on about 28 March 1988. A rational and highly likely scenario was hypothesized that encompassed all of the most credible probabilities.

1 Introduction

Background

In March 1988 the Explosion Effects Division (EED), Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES), was contacted by Mr. Glenn Leach of Rock Island Arsenal, Rock Island, IL, concerning a recent incident which occurred during routine milling operations on a rocket propellant grain at the Radford Army Ammunition Plant, Radford, VA. A machinist was in the process of milling down a 787.4-mm (31-in.) long by approximately 76.2-mm (3-in.) diameter "dowels" of solventless double-base (nitrocellulose-nitroglycerin) rocket propellant to its final diameter of 69.85 mm (2.75 in.) when an explosion and fire occurred. The machinist was killed and the machining bay and room were severely damaged. The EED was asked to provide expert consultation to COL Lawrence Stock who was at the site of the incident conducting an Official Board of Inquiry into the accident. COL Stock's main concern was to determine the precise location at which the explosion initiated. Mr. L. K. Davis, Chief, EED, tasked Mr. J. K. Ingram to assist with the analysis. Experts were polled both in EED and the associated Structural Mechanics Division (SMD), SL. From the information in-hand, the problem of precisely determining the origin and cause of the explosion and fire appeared to be formidable. In subsequent discussions with Mr. Leach, additional information came to light, clarifying the scenario. Based on the available information, the following hypothesis was developed to describe the probable chain of events leading to the explosion.

Objective

The objective of this study was to develop a rational and highly likely scenario to explain the events leading up to a fatal detonation that proceeded from routine machining of a small rocket propellant grain.

Scope

This report describes the most probable sequence of events that would have had to occur to cause a fire and subsequent detonation during routine propellant machining operations.

2 Assessment

Initial Scenario

The milling machine used a four-head cutter to trim the outside dimension of the double-base propellant grain from the rough extrusion dimension of just under 76.2-mm (3-in.) diameter down to 69.85 mm (2.75 in.) for insertion into a Mark-90 rocket motor housing. A propellant chip (cuttings) collector pipe with flared top was provided just below the cutter head (Figure 1a). A combined compressed air/water mist chip remover system was attached in a horizontal configuration to the left of the cutter head (viewing from the cutter head end of the lathe). The combined air/water mist spray washed the propellant cuttings down into the collector pipe (approximately 101.6- to 127-mm (4- to 5-in.) diameter at the top portion, just below the flared section, but which is stepped-down to a smaller diameter pipe below the upper section), Figure 1b. The discharge pipe fed into a slurry system which transported the cuttings to a collection weir where they were removed for disposal. The lathe was covered by a 6.35-mm (0.25-in.) thick aluminum shroud which was designed to provide flash-fire protection for the building in case of a propellant fire. The aluminum shroud was not sealed and provided no real containment and, therefore, would not have provided adequate pressurization to cause a propellant fire to lead to detonation.

Postulated Sequence of Events

The following sequence of events leading to the fire and subsequent detonation event are suggested as the probable scenario:

a. Cutting transport system failed (Figure 1c).

b. Or did not remove the accumulated cuttings rapidly enough.

(1) The machinist may have been cutting the propellant at too rapid a rate.

(2) A portion of the propellant may have broken off and lodged in the removal pipe, causing a blockage.

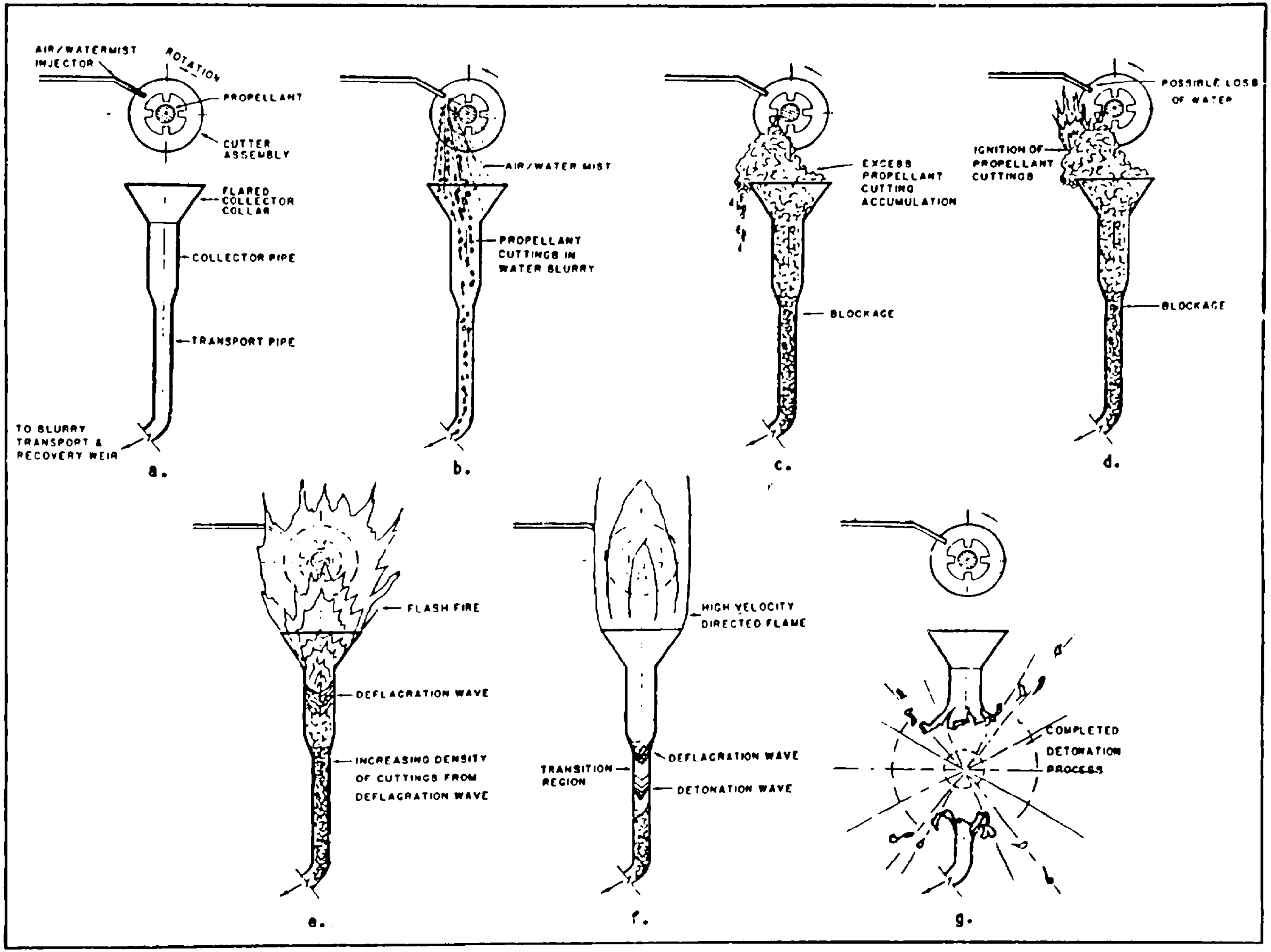

Figure 1. Postulated point of detonation and detonation sequence

(3) The air/water mist system may have failed, leaving only dry, compressed air to remove the cuttings (Figure 1d).

(4) Any combination of b(1) through b(3) could have occurred.

c. An excess of propellant cuttings accumulated up to the vicinity of the cutter head (Figure 1d).

d. The excess, dry cuttings were ignited (Figure 1d).

(1) From excess heat build-up.

(2) From a spark.

(3) From static build-up and discharge.

f. The subsequent deflagration propagated into the discharge pipe (which likely was full of dry propellant cuttings), Figure 1e.

g. The deflagration velocity jumped to detonation wave speed (Figure 1f)

(1) If sufficient confinement was present.

(2) If the pressure remained or increased such that the detonation wave was sustained (Figure 1f).

h. An explosion would have then been probable (Figure 1g).

i. Sympathetic detonation of the remaining propellant "dowels" could have occurred (if it was not already consumed by the initial fire).

Supporting Observations

Portions of the collection pipe away from the flared end were missing or broken into small pieces, whereas portions of the pipe nearest the flared end were in larger pieces or were only cracked, showing indications of having been burned. This evidence strongly supports the foregoing probable sequence of events.

3 Conclusions

Overview

Double-base propellants are relatively insensitive and are difficult to ignite, and are even more difficult to detonate in small volumes and unconfined. It is highly unlikely that the wet propellant chips would have reasonably ignited unless subjected to a direct, sustained, intense flame. It is far more likely that the compressed air/water mist system was either not turned on, or failed at some point in time after the machining operation was begun. The most probable scenario would require failure of the water mist system and significant chip build-up and blockage of the cuttings removal pipe, either by dry cuttings or by pieces of broken propellant (or foreign matter), with dry cuttings backing up above the blockage. A significant accumulation of dry chips up to the vicinity of the cutting head could have been ignited by sustained friction, especially if the cutting rate was excessive or if the cutting bits were dull or broken. An alternative possibility is that dry air blowing over the accumulation of propellant chips (or related conditions) set up a sufficient static electrical charge that sparked, igniting the chips.

Once ignited, the deflagration rate of the propellant chips would have been extremely rapid. Deflagration under certain conditions will proceed to a detonation, if the deflagration wave speed is caused to increase suddenly to a velocity sufficient to initiate a detonation pulse, and if the resulting detonation wave can be sustained without dropping below the critical wave velocity. One of two factors (or a combination of both) can contribute to the required velocity wave speed jump:

a. Sufficient pressurization (or containment).

b. Sufficient increase in detonable material density.

If, in fact, the cuttings collector pipe was equipped with a flared upper section, and reduced to a smaller diameter pipe lower down, then conditions would have been reasonable for a velocity wave speed jump to have occurred. As the cross-sectional area of a confined propellant/explosive is decreased, the effective confinement increases and the wave velocity increases. As the

wave velocity increases, it tends to compress the material in front of the leading wave front, increasing the material density and, at the same time increasing the internal pressure.

Significant additional pressure is added from the large volume of hot gases released in the burning process associated with propellant materials. All of these factors can act in synergism rapidly to cause the propagation wave velocity to jump from subcritical to a critical detonation wave velocity, thereby initiating a detonation wave. If the containment (i.e., the pipe in this incident) remains intact for a sufficient period of time, the detonation wave can continue to a full detonation of the available propellant/explosive in front of the wave, at least down to the point of constriction.

It is also possible that the remaining propellant "dowels," if not already consumed by the initial fire, could have been sympathetically detonated by the initial explosion, which probably occurred in the cuttings removal pipe.

A key question in this incident is whether a fire or an explosion took place first. The answer might be obtained by a microscopic physical and chemical analysis of some of the metal parts that were close to the source. Perhaps the bed of the milling machine (lathe) might be the best place to look for "projectiles," in the form of small fragments, that issued from metal near the source (the aluminum shield?) and embedded themselves in the lathe frame. If the fire took place first, there will be combustion products between the fragment and machine part. If the fire followed the explosion, the combustion products will be confined to the outside of the machine and fragment.

Should it be verified that the explosion occurred first, then one might look for:

a. A very high current static discharge.

b. An impurity in the propellant that was impact sensitive (primer-like).

c. A shock-sensitive material accumulation, such as droplets of reconstituted nitroglycerine within the outer layers of the propellant grain (particularly if the grain was old), of sufficient quantity to detonate on impact with the cutters.

A further benefit of a micro-analysis would be the possibility that the source could be determined form the direction of the impact paths of several fragments. At such close ranges, the particle paths would be near straight lines.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 1993	Final report

4. TITLE AND SUBTITLE
Assessment of Accident at Radford Army Ammunition Plant

5. FUNDING NUMBERS

6. AUTHOR(S)
James K. Ingram

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
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Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report
SL-93-22

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Munitions and Chemical Command
Rock Island Arsenal, IL 61299-6000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A desk study was conducted to assess probable sequences of events that could have led to a flash fire and subsequent lethal explosion of a double-base rocket propellant grain being machined to final dimensions. The incident occurred at the Radford Army Ammunition Plant, Virginia, on about 28 March 1988. A rational and highly likely scenario was hypothesized that encompassed all of the most credible probabilities.

14. SUBJECT TERMS
Explosive hazard — Fire detonation
Fatality — Propellant

15. NUMBER OF PAGES
14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		